AD-E440 081

(12) LEVEL III

AD

AD A088539

TECHNICAL REPORT ARLCB-TR-80024

A MATHEMATICAL MODEL FOR PRODUCTION SIMULATIONS

E. E. Coppola

July 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

AMCMS No. 3291.06.7751

PRON No. M1-7-P0873-M7M7

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

80 8 18 024

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARLCB-TR-80024	2. GOVT ACCESSION NO. AD-A088539	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A MATHEMATICAL MODEL FOR PRODUCTION SIMULATION		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) E. E. Coppola		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Armament Research and Development Command Benet Weapons Laboratory, DRDAR-LCB-TL Watervliet, N.Y. 12189		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 3291.06.7751 DA Project. PRON No. M1-7-P0873-M7M7
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research and Development Command Large Caliber Weapon System Laboratory Dover, New Jersey 07801		12. REPORT DATE July 1980
		13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Computerized Simulation
Mathematical Model
Production Model
Production Scheduling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A mathematical model has been developed to simulate the production lines at Watervliet Arsenal. Inputs to the model include the steps required to transform raw material into a finished product and the resources available for production. From these data, the model will predict such things as the number of items produced by the line, utilization of machines and workers and areas where the number or quality of the resources are not adequate to meet the desired production goals.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

A mathematical model, with a computer implementation, has been developed to simulate the production lines at Watervliet Arsenal. The model takes a description of the steps required to transform raw material into a finished product and a list of the machines and workers available for production. From these data, the model will predict such things as:

1. The output of the line in number of items produced per month.

2. Utilization of machines and workers.

3. Areas where the number or quality of machines and/or workers is not adequate to meet desired production goals.

Description of the Mathematical Model

Raw material is transformed into a finished product by subjecting it to a well-defined sequence of operations. The operations are performed by means of equipment operated by workers. Some pieces of equipment will occasionally go down, either for scheduled maintenance or to correct an unscheduled failure. Each worker, because of physical constraints and his experience and skills, can only perform certain tasks. Furthermore, workers do not work all day; at some point, they leave and are replaced by a new shift.

The mathematical model is an abstracted, idealized version of the above. The model has five key elements which we will examine in detail: items, production processes, facilities, workers and queues.

The items are the things being produced. They arrive at the plant in a raw state and are then converted into finished products.

A production process is a list of steps, or operations, performed in a certain sequence. There may be more than one production process, in which case the different processes correspond to different end items. For example, a given plant may produce two products; let us call them "widgets" and "gadgets". The widgets may have a production process that could be represented schematically as follows:

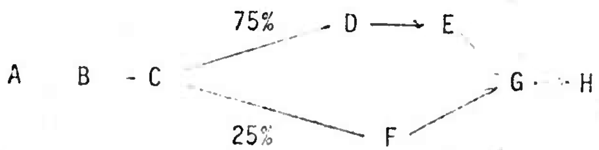
$$A \longrightarrow B \longrightarrow C \longrightarrow D$$

This means that the raw widget goes through steps A, B, C and D in that order. At the end of step D, the widget is finished and ready for shipping. The gadgets, on the other hand, may have a production process given by the diagram:

$$E \longrightarrow F \longrightarrow G \longrightarrow H$$

On arrival at the plant, each raw item is marked as to whether it will ultimately become a widget or a gadget. A widget cannot be transformed in mid-process to a gadget. Once a raw item enters the widget process, it must complete the widget process, in exactly the order specified for widgets.

The definition of the processes is somewhat freer than the above examples imply. There is provision, for example, for alternate routes. For example, we might have a production process represented by:



Now 75% of the items pass through steps D and E after step C, while 25% of the items pass through step F.

Facilities

The facilities are the pieces of equipment used to perform the operations in the production processes. For each step in a production process, there is a list of alternative facilities that can be used to perform the operation of that step. So the widget process above would be more fully described by:

$$\begin{array}{ccccccc} 1 & & 2,3 & & 4 & & 1,3 \\ A & \rightarrow & B & \rightarrow & C & \rightarrow & D \end{array}$$

Here we have four facilities, labeled 1 through 4. Step A requires the use of facility 1. Step B can be performed either with facility 2 or facility 3. Step C requires facility 4, and step D requires either facility 1 or facility 3. It is permissible for one facility to be used in more than one step. It is also possible to "mix and match". In the diagram above, for example, either facility 2 or facility 3 can be used in step B, but facility 2 cannot be used in step D, even though facility 3 can be used in that step. Note that when several facilities are listed for a step, they are assumed to be in parallel; that is, any one of the facilities alone will suffice to complete the step.

Associated with each facility used in a step is a process time. This is the time in hours required to complete the step using that facility. A fuller description of the process shown above might be:

1 (2.0)	2 (1.5) 3 (1.3)	4 (3.0)	1 (1.5) 3 (1.3)
A	B	C	D

The numbers in parentheses are the process times. Note that a facility used in several steps may have different process times and that a step with several facilities may have different process times for each facility.

For the purposes of our model, we envision each facility as being enclosed in a box with two doors, one labeled "in" and the other labeled "out". An item enters the box through the in door, is worked on by the facility and exits the box through the out door. Only those items that are being operated on by the facility are in the box. Items cannot wait for service in the box.

The box analogy leads to a convenient way of describing the facilities. Some facilities can operate on only one item at a time, but others can process items in batches. So we envision the items as entering the box in batches. A batch, of course, may consist of only one item. Each facility has a maximum and a minimum entry. The minimum entry is the smallest number of items in a batch allowed to enter the box. The maximum entry is the largest number of items in a batch allowed to enter the box. Each facility also has a maximum capacity. The maximum capacity is the largest number of items that can be in the box at one time; that is, the maximum capacity is the largest number of items that the facility can handle at one time.

Let us also envision that the in doors of each box have locks on them. At certain times, the door may be locked and then no batches can enter until the door is unlocked. We can classify all facilities into two types: locking and unlocking. For locking facilities, the door is automatically locked every time a batch enters and is not unlocked until the batch leaves. Locking facilities are, therefore, those that can process only one batch at a time. Unlocking facilities are those that can process several batches simultaneously. For unlocking facilities, the door is locked only when the entry of another batch would force the facility above its maximum capacity. Otherwise, batches meeting the minimum entry requirements may enter freely. (A batch which is too large is broken down into smaller batches so the maximum entry requirement is never in itself a bar to entry. The maximum entry only places an upper bound on the number of items entering at any one time.)

A few illustrations might clarify these points and show how some situations can be handled in terms of the model.

a. Lathe. A widget is to be machined on a lathe at some point in its production process. The lathe can operate on only one item at a time. So items must "enter" the lathe in batches of one. The description of the lathe is:

Minimum entry: 1

Maximum entry: 1

Maximum capacity: 1

Locking/unlocking: locking

b. Conveyor Belt. Widgets are transported from one place to another by a conveyor belt. Because of size and weight restrictions, the belt can carry at most 20 widgets at one time. The widgets are put on the belt one at a time, i.e., in batches of one. The belt is unlocking because it processes several batches simultaneously. The description of the belt is:

Minimum entry: 1

Maximum entry: 1

Maximum capacity: 20

Locking/unlocking: unlocking

c. Oven. Widgets require a heat treatment at one point in their production process. They must spend one hour in an oven. The widgets are loaded into racks and then placed in the oven. Each rack can hold a maximum of ten, but for various reasons, a rack will be loaded with only eight or nine widgets if ten are not immediately available. This oven holds four racks and racks may be placed in the oven at any time without disturbing those already there. In terms of the model, the oven may be described:

Minimum entry: 8

Maximum entry: 10

Maximum capacity: 40

Locking/unlocking: unlocking

d. Truck. After the heat treatment, widgets are transported to another building by a truck which can carry no more than 30 widgets at a time. The truck picks up the widgets at a loading dock. When the truck arrives at the dock, the widgets waiting there are loaded into the truck. The truck takes off if at least ten widgets have been loaded; otherwise, it waits until at least ten widgets arrive at the dock. Since no widgets can "enter" the truck while it is enroute, the truck is locking. Since the truck can operate on no fewer than ten widgets at a time, the minimum entry is ten. In model terms, the truck may be described:

Minimum entry:	10
Maximum entry:	30
Maximum capacity:	30
Locking/unlocking:	locking

The majority of facilities used at Watervliet Arsenal are like the lathe described above: they are locking and have minimum entry, maximum entry and maximum capacity equal to one.

Failure and Maintenance

Some facilities occasionally breakdown or must be taken out of service for a scheduled maintenance a tion. The model at present does not distinguish between planned and unplanned outages. Whenever a facility is taken out of service, the facility is said to have experienced a "failure" and the actions necessary to bring the facility back into service are called "maintenance" or "repair". Note that the term "failure" is used somewhat differently than it is normally used in reliability theory. In the model, a "failure" is <u>any</u> occasion when the facility is taken out of service, while <u>in</u> reliability theory, outages for scheduled maintenance are not considered failures.

The pattern of failure and maintenance actions is described by two numbers: the mean operating time to failure (MOTTF) and the mean time to repair (MTTR). The MOTTF is the average time that the facility is actually in use between successive failures. The MTTR is the average time required to bring the facility back into service after a failure. The MOTTF is a measure of how often the facility fails, while the MTTR is a measure of how long the facility is out after a failure.

In the model, failure and maintenance times are always random. At present, provision is made only for exponentially distributed random variables, but the exponential distribution seems to give a reasonable approximation to real-life breakdown data for some Watervliet equipment examined by the author. In the computer implementation of the model, random variables are generated with the required means for both operating time to failure and time to repair.

The MOTTF and MTTR should be estimated from historical data, so we will briefly indicate here how to estimate these quantities. Examine the usage and maintenance data of the facility over whatever time period such data are available. Add up the number of hours the facility was actually operated; this is the total operating time. Add up the total number of hours that were spent maintaining the facility; this is the total repair time. Count the total number of failures. The estimates of MOTTF and MTTR are given by:

$$\text{MOTTF} = \frac{\text{total operating time}}{\text{number of failures}}$$

$$\text{MTTR} = \frac{\text{total repair time}}{\text{number of failures}}$$

Workers, Crews and Shifts

Workers are the people who operate and maintain the facilities. In the model, there is no hard and fast distinction made between operators and repairmen. It is possible to specify that a given worker may be assigned to either operating or repair.

Workers are organized into "crews" and "shifts". Each crew has the responsibility for certain tasks and, in a sense, is defined by the tasks assigned to it. A task assigned to a given crew can be performed only by a member of that crew. Conversely, a worker can perform only those tasks assigned to his crew. Every worker is assigned to only one crew. There is no overlap among crews. However, within a crew, each worker is considered interchangeable with any other member of his crew. In order words, if any crew member is qualified to perform task X, then all the members of his crew are qualified to perform task X.

Some facilities (e.g., automated machines) do not require operators. Some facilities may require more than one operator. Both of these situations are accepted by the model. Each facility that requires operators must be assigned an operator crew. This is the crew that operates the facility. Each facility that can fail must be assigned a repair crew. This is the crew that has responsibility for maintaining the facility. It is permissible for one crew to be responsible for both operating and maintaining the facility. It is permissible to specify that a facility requires no repairmen or more than one repairman for a maintenance action. Note also that there is an implicit assumption that each facility can be operated by members of only one crew and similarly for maintenance.

The crew concept is a way of modeling the division of workers by skill and location. The shifts model the behavior of workers over time. Normally there are three shifts, although the model makes no assumptions about the number of shifts. There are special actions that occur at a shift change that will be discussed below.

Queues

The last major element of the model are the queues. There is one queue for each step in each production process. The queue is a holding area for items waiting to be serviced by a facility specified for that step. The queues are assumed in the model to be as large as they need to be. More will be said of queues below.

The Movement of Items

The totality of facilities, steps, workers and queues will be called the "system". In a sense, a manufacturing plant is like an obstacle course. The items must move through the plant in the least amount of time possible but they must follow certain courses. Obstacles are continually placed in the way: a machine goes down, or there are not enough workers to handle all the items.

The raw items enter the system at a predefined rate (for example, 50 widgets and 25 gadgets per day). Each raw item is assigned to a production process, which is essentially a road map telling how the item is to move through the system. For each step there is a list of facilities; the item has the option of "visiting" any one of these facilities. It stays at the facility a certain length of time (the process time) and then moves on to the next step, until finally the item has completed all steps and exits the system.

It is quite possible that as the items move through the system, there are conflicts on the resources of the system. For example, there may be several items that could all be serviced by the same facility but not simultaneously. A rule is needed for deciding which items are to be serviced first.

Each item type is assigned a priority. For example, we may give widgets first priority and gadgets second priority. The model allows for different types to have the same priority, if desired. There are two rules for scheduling service:

(1) Higher priority items are serviced before lower priority items if possible.

(2) If there is a conflict between items of the same priority, then the one that has been waiting the longest for service gets it first, if possible.

As an illustration, consider the following situation: widgets and gadgets are moving through the system. At step Y, widgets must be operated on by Facility X. At step Z, gadgets must be operated on by Facility X. Facility X can operate on only one item at a time and both widgets and gadgets have a process time of one half hour on Facility X. Facility X is the only facility listed for these steps and is listed for no other steps. Widgets have higher priority than gadgets. We assume for the moment that there are sufficient workers in Facility X's operator crew that there is always an operator available when Facility X needs one.

Let us start observing Facility X at 9:00. There are one widget and five gadgets waiting for Facility X. Facility X has just completed operation on an item and is ready to accept another item. There are six items from which Facility X could choose. It selects the one of highest priority, the widget, and begins work on the widget. At 9:15, a widget arrives from another step. The widget cannot "enter" Facility X (it is locked) and there are no alternatives. The widget then enters the queue for Step Y and waits there. At 9:25, a gadget arrives. There are already gadgets in the queue for Step Z and so the new gadget is put into the queue behind the five already there. At 9:30, Facility X is done with the widget. The widget leaves Facility X and goes on to its next step. Facility X now looks around for more work. There are seven possible items that it could work on. It selects the one of highest priority, the widget, and begins work on it. Nothing more happens until 10:00 when Facility X is done with the widget. Again it looks for more work. There are six gadgets waiting. All have the same priority, so Facility X selects the one that has been waiting the longest and begins work on it.

The scheduling can be affected by Facility X failing. If a facility fails, it cannot operate on any items until it is restored to service.

Furthermore, as seen later, Facility X may lose its operators if its operator crew has higher priority jobs elsewhere. In that case, all items desiring Facility X must either wait until Facility X's operator crew has completed all higher priority jobs or else find an alternative.

The Shift Change

At shift change, all the workers leave (with the one exception noted below) and a new set of workers arrives. These new workers must be assigned jobs and the assignment requires some rules, for there may not be enough workers to do all the jobs that require doing.

Before going into how the workers are assigned, let us describe what happens to the jobs in process at shift change. Jobs are divided into two categories: continuous and halting. Halting jobs are those that can be stopped at any time and then be resumed later after possibly some delay. Continuous jobs are those that, once started, must be completed with no interruption.

At shift change, all halting jobs are halted. If the job is an operation, then the items on the halted facility remain in the facility and are not returned to queue.

When a halted job is resumed, it is taken up from the point where the halt occurred. For example, if a job requires one man-hour to complete, then exactly one man-hour will be expended on that job, regardless of how often the job is halted and resumed.

Continuous jobs by their nature cannot be stopped. So the first priority of the incoming shift is to relieve all workers on continuous jobs. If there are not enough workers to do this, then as many workers as required from the outgoing shift are detained so that all active continuous jobs are covered. The detained workers are released at the earliest opportunity.

Any workers remaining after continuous jobs have been covered are assigned to jobs in the following order:

(1) Finishing halted maintenance jobs.

(2) Finishing halted operating jobs.

(3) Beginning new maintenance jobs.

(4) Beginning new operating jobs.

At all times, the usual priority rules are followed: items of higher priority are serviced before items of lower priority, whenever possible; and among items of the same priority, those which have been waiting the longest for service are serviced first, whenever possible. Workers and facilities are always kept as busy as possible.

Assignment of Workers During Shift

When a job is completed, the worker(s) on that job are released from the job and are assigned to a new, possibly different job. The priority of job assignment during shift is the same as that at shift change, except that during shift continuous jobs are treated no differently than halting ones.

Computer Implementation

The computer program PRDLN has been developed to exercise the model for a real or planned production line. Input data to the program consists of descriptions of the production processes, facilities and workers. Output from the program includes production figures, facility and worker usage, and queue data to identify "bottlenecks" in the system. Preparation of the input data is discussed in Appendix A. An example and explanation of the output is given is Appendix B.

Conclusion

The model and its computer implementation have been tested with satisfactory results on real-life data from Watervliet Arsenal. The model was able to identify problem areas correctly, and to give reasonable predictions for production figures.

One practical limitation of the model is that for a large production line, the required amount of computer space and time is large. However, it is difficult to see how a simpler model could achieve results consonant with real life situations.

APPENDIX A

INPUT DATA FOR PRDLN

General

The input data for program PRDLN are normally placed on standard punched cards. The cards are arranged physically into files, each of which will be described in detail below.

As PRDLN is written in the FORTRAN language, standard FORTRAN input concepts are used. For those unfamiliar with such concepts, we will give here a brief summary of the information needed for PRDLN input data.

A field is a set of contiguous card columns where a piece of data is punched. PRDLN uses three types of data fields: literal, integer and real.

In a literal field, any valid characters, including numbers, letters, punctuation signs and blanks, may appear in any order. The order in which the characters appear is significant, as is the placement of the characters in the field. If the program is to recognize two literal fields as being identical, they must be completely identical. For example, (the symbol b represents a blank) the computer will not recognize bYES and YESb as being identical, even though both fields appear to contain only the word "yes". The difference is that in the first field, the blank precedes the word, whereas in the second field, the blank follows the word.

Integer fields, as the name implies, are used for integer data. One number is read in from each integer field. Only numerics (0, 1, 2, 3, etc.), blanks and plus and minus signs (+ and -) may appear in an integer field. A plus sign is never required, as an unsigned non-zero number will always be assumed to be positive. If a plus or minus does appear in the field, it must appear to the left of any numerics, and there may be no more than one sign per field.

FORTRAN automatically replaces all blanks in an integer field by zeroes. So the placement of the characters in the field is significant. A number in an integer field should always be right-justified in the field. For example, the field b2bb will be converted on input into 0200, and interpreted by the computer as the number "two hundred". If the user intended the number "two", then he should have written it as bbb2 or 0002.

Real fields are used for numbers that may have fractional parts. One number is read from each real field. Data in a real field may be written in three different ways. First, if the number is an integer, then it may be written the same as in an integer field, with all the rules of integer fields applying. Second, the number may be written as a decimal. In this format, only numerics, blanks, a plus or minus sign and a decimal point may appear. As in integer fields, the plus sign is not required, there may be no more than one sign per field and the sign (if any) must appear to the left of the numerics and decimal point. There must be one and only one decimal point per field, which may appear anywhere in the field (except to the left of a plus or minus sign) as convenient. Digits to the left or right of the decimal point are not required. As with integer data, blanks are replaced by zeroes. For example, the number .2 may be written in a four column real field in any of the following ways (the symbol b represents a blank): .2bb, b.2b, 0.2b, b.20, bb.2. Note, however, the field b.b2 is converted on input to 0.02, and so is interpreted by the computer as ".02" and not as ".2".

The third method for writing data in a real field, the "E format", will not be discussed here. The two methods given should suffice for the vast majority of real data encountered in practice.

Defaults

Many of the data items have default values. The default value is assumed whenever a field is left blank or a non-literal field contains the number zero. The default value is generally the one must often encountered in practice. Defaults are provided to reduce the amount of coding and punching required.

Error Checking

The input routines will go through the input data and check them for internal consistency and completeness. Further, there are limits to the number of data items that the program can handle, and any attempt to go beyond those limits will be blocked by the program.

Upon detection of an error, the program will print a message to the user describing the error. If any errors are detected, the program will automatically stop after reading and checking the input data.

SYSIN File

The SYSIN file contains general system information and information concerning the shifts. The file consists of: a title card; two time cards; and shift cards, one for each shift.

(1) Title Card:

This card contains a line which is printed on the top of each page of output. All eighty columns are used and the field is literal. Default is 80 blanks.

(2) First Time Card:

This card contains one integer field in columns 1 through 4; the rest of the card is ignored. The field contains the number of days in one month. Default is 20.

(3) Second Time Card:

This card contains four integer fields as follows:

(a) Columns 1 through 4. The number of months on which the simulation output is to be based. Default is 1.

(b) Columns 5 through 8. The number of months in the "warm-up" phase of the program. The simulation starts with no items in the system and so it requires a "warm-up" period to get to a steady-state condition. The "warm-up" months are in addition to the months specified in the first field of the card. Only the state of the system at the end of the "warm-up" period is preserved. Results such as the number of items produced during "warm-up" are discarded and do not appear in the output listings.

(c) Columns 9 through 12. The total item storage capacity. This number is the maximum number of items (of all and any type) that can be in the system at one time. Default is 500. Specifying a total item storage capacity of more than 500 is an error.

(d) Columns 13 through 16. Random generator start-up. The number in this column determines the starting point of the random-number generator of the program. Default is zero.

(4) Shift Cards:

There must be at least one shift card. Each card has the same format:

(a) Columns 1 through 8. A literal field containing the name of the shift. Default is 8 blanks.

(b) Columns 9 through 16. A real field containing the number of hours in the shift. There is no default. Specification of zero or a negative number of hours is an error.

(c) Rest of card: Not read.

The shift cards must be listed in the actual order in which the shifts occur, although it is not necessary that the first shift listed be active at midnight.

Crew File

The crew file consists of one crew card for each crew. There must be at least one crew card. The crew cards have the following format:

(1) Columns 1 through 8. The name of the crew. The field is literal. Default is 8 blanks. Each crew name must be unique. The use of the same name on two crew cards is an error.

(2) Columns 9 through 12. The number of crew members in the first shift listed in the SYSIN file. Default is zero. The field is integer.

(3) Columns 13 through 16. The number of crew members in the second shift (if any) listed in the SYSIN file. Default is zero. The field is integer.

(4) Columns 17 through 20. The number of crew members in the third shift (if any) listed in the SYSIN file. Default is zero. The field is integer.

(5) Rest of card: Not read.

Facility File

This file consists of one card for each facility. There must be at least one facility card. The cards have the following format:

(1) Columns 1 through 8. Facility serial number. The field is literal. The "serial number" need not be an actual number. Since the field is literal, any combination of characters and blanks is acceptable; e.g., A#B2?0Z* is an acceptable "serial number". There is no default. The serial number must be unique. The use of the same serial number on two facility cards is an error.

(2) Columns 9 through 24. Facility name. The field is literal. Default is 16 blanks. This field is not checked by the program.

(3) Columns 25 through 32. Operator crew. This field, which is literal, contains the name of the operator crew of the facility. The name must be written exactly as it appears on the crew card. This field is ignored if the facility requires no operators (see below); otherwise a valid crew name must appear in this field. There is no default.

(4) Columns 33 through 40. Maintenance crew. This field, which is literal, contains the name of the maintenance crew of the facility. This field is ignored if the facility never fails or if the facility does not require repairmen; otherwise a valid crew name must appear in this field. There is no default.

(5) Columns 41 through 48. The mean operating time to failure (MOTTF) of the facility in hours. This is a real field. A blank, zero or negative number in this field indicates that the facility never fails.

(6) Columns 49 through 56. The mean time to repair (MTTR) of the facility in hours. This is a real field. This field is ignored if the facility never fails. Default is zero.

(7) Columns 57 through 60. Minimum entry of the facility. This is an integer field. Default is one.

(8) Columns 61 through 64. Maximum entry of the facility. This is an integer field. Default is to set the maximum entry equal to the minimum entry. If the number in this field is less than the minimum entry, then the maximum entry is automatically set equal to the minimum entry.

(9) Columns 65 through 68. The maximum capacity of the facility. This is an integer field. Default is to set the maximum capacity equal to the maximum entry. If the number in this field is less than the maximum entry, then the maximum capacity is automatically set equal to the maximum entry.

(10) Columns 69 through 72. The number of operators required to operate the facility. This is an integer field. Default is one. A zero value in this field is automatically changed to one. To specify that no operators are required, a negative number (any negative number will do) must appear in this field. Conversely, a negative number in this field is automatically changed to zero.

(11) Column 73. Locking or unlocking. This is a literal field. Any non-blank character in this field indicates that the facility is unlocking. A blank indicates locking. Default is locking.

(12) Column 74. Disposition at shift change for operation. This is a literal field. Any non-blank character indicates continuous disposition. A blank indicates halt disposition. Default is halt. A facility requiring no operators is automatically made continuous disposition regardless of the contents of this field.

(13) Columns 75 through 78. Number of repairmen required to repair the facility. This is an integer field. This field is ignored if the facility never fails. Otherwise, the default is one.

A zero value in this field is automatically changed to one. To specify that no repairmen are required, a negative number must appear in this field.

(14) Column 79. Disposition at shift change for maintenance. This is a literal field. Any non-blank character in this field indicates halt disposition. A blank indicates continuous disposition. Default is halt disposition. A facility which never fails or which requires no repairmen is automatically made continuous disposition, regardless of the contents of this field.

(15) Column 80: Not read.

The order in which the facility cards appear in the file will be the same order in which the facilities appear on the output listings. Otherwise the order is not significant.

Process File

Each process file describes the production process of an item type. There must be at least one process file. The process files are read in order of priority of the item-types. How this is to be accomplished will be described below. Higher priorities are read before lower priorities. The first card of each process file is a type name card, whose format is:

(1) Columns 1 through 8. Item-type name. This is a literal field. Default is 8 blanks. Item-type names are not required to be unique, but should be.

(2) Columns 9 through 12. The maximum storage capacity for this type. The field is integer. Default is to set the maximum storage capacity for the type equal to the total item storage capacity.

(3) Column 13. Priority. This is a literal field. This field is ignored in the first process file to be read in, which is assumed to be the process file of an item type of highest priority. On subsequent process files, this field indicates whether the item type is to have the same or lower priority than the previous item type. A blank in this field indicates the same priority; any non-blank character indicates lower priority.

(4) Rest of card: Not read.

The name card is followed by item-input cards, which indicate how raw items are to be introduced into the system. There must be at least one item-input card in each process file.

Each item-input is specified by four numbers - the number of items to be input (N), the time between inputs (T), the time to first input (F), and the step in the production process at which the items are to be input. T and F are both in hours. At F hours after the start of the simulation, N items are introduced into the system at the specified step. Thereafter at intervals of T hours, N items are introduced. So the first input of N items is made at F hours, the second input at F + T hours, the third input at F + 2T hours, etc. In actuality, N items may not be introduced at each input time. The storage capacities are never violated. Only as many items are introduced as would allow the system to stay within the storage capacities. For example, if there are 280 items in the system at an input time, the number of items to be input is 30 and the total item storage capacity is 300, then at most 20 items are input. If the system is full (i.e., at its total item storage capacity) at an input time, then no items are input.

The item-input cards have the following format:

(1) Column 1. This is a literal field. A blank in Column 1 indicates that another item-input card follows; any non-blank character indicates that no more item-input cards follow.

(2) Columns 3 through 5. The number of items (N). This is an integer field. Default is to set the number of items equal to the maximum storage capacity for the type.

(3) Columns 6 through 13. The time between inputs (T) in hours. This is a real field. Default is to set the time between inputs equal to the number of hours in one day.

(4) Columns 14 through 21. The time of the first input (F) in hours. This is a real field. Zero is the default. A negative number in this field is changed to zero.

(5) Columns 22 through 25. The step number of the step at which the items are to be input. For an explanation of the term "step number", see below. Default is the first step to appear in the process file.

(6) Rest of card: Not read.

The rest of the process file consists of step packets. Each step packet describes a step in the production process. There must be at least one step packet in each process file.

The step packet consists of one step card followed by as many step-facility cards as required. Each step packet must contain at least one step-facility card. The step card identifies and describes the step. The step-facility cards provide a list of the facilities used in the step and give instructions on process times, next steps, etc.

Each step has associated with it a list of facilities that may be used in that step. The program organizes this information as "step-facility combinations". A step-facility combination is an ordered pair (x,y) where x is a step and y is a facility used in that step. With each step-facility combination there are associated four pieces of data:

(1) A process time. This is the length of time required to perform step x using facility y.

(2) A next step. This is the step to which items are normally routed <u>after</u> completing step x using facility y.

(3) A probability of splitting. The user may, if desired, "split" the items leaving facility y on completion of step x. Some items will go the next step, and other items will go a "split step". The probability of splitting is the proportion of items that go to the split step.

(4) A split step.

These four pieces of data will be called the step-facility attributes. It should be emphasized that the step-facility attributes are properties of the step facility <u>combination</u> and not of the step or of the facility per se. A step may have several distinct step-facility combinations and each combination may have different attributes. For example, step x using facility y may require one hour, but step x using facility z may require two hours. Similarly, a facility used in several steps may have different attributes for each combination it defines.

The step card identifies the step and defines the default attributes for each of the step-facility combinations of that step. The step-facility cards provide a listing of the facilities used in the step and may contain information about the attributes that overrides the default attributes. In addition to the default attributes provided in the step card (the explicit defaults), there are system defaults built into the program. So the step-facility attributes have defaults provided by the program, which may be overriden by the user's explicit defaults on the step card.

The program checks each step-facility card for the step-facility attributes. If an attribute is not stated on the step-facility card, then the program checks to see if there is an explicit default on the step card. If there is no explicit default, then the system default applies. Entries on the step-facility cards override explicit defaults, which override system defaults. The explicit defaults are provided to reduce the amount of coding (and potential for error). A step with 20 facilities requires 20 step-facility cards. If these all have the same attributes, then the attributes need be coded only once, on the step card.

For each production process, two special steps are automatically created, an EXIT step and a SCRAP step. Both of these steps cause an item to leave the system. Items passing through the EXIT step are added to the production figures, while items passing through the SCRAP step are not added to the production figures. The EXIT and SCRAP steps are created programmatically and require no facilities. The user should not attempt to define his own EXIT or SCRAP steps. The EXIT step may be specified as a next step and the SCRAP step may be specified as a split step.

System defaults for the step-facility attributes are:

(1) Process time. There is no default.

(2) Next step. The step physically following in the process file, if there is one. Otherwise, default is the EXIT step.

(3) Probability of splitting. Default is zero.

(4) Split step. Default is the SCRAP step.

The format of the step card is:

(1) Columns 1 through 4. Step number. This is a literal field. Although the term "step number" is used, the "step number" need not be numeric. It can consist of any combination of blanks and any characters. For example A?5* is an acceptable "step number". Step numbers are not required to be unique, although two identical step numbers in the same process file can cause unpredictable results. However, there are no complications caused by using the same step number in different process files. EXIT and SCRAP should not be used as step numbers and the step number should contain at least one non-blank character.

(2) Columns 5 through 20. Step name. This is a literal field. This field is provided purely for the convenience of the user in interpreting the output listings and is not checked by the program.

(3) Columns 21 through 28. Explicit default process time in hours. This is a real field. Remember that there is no system default for process time, so if this field is left blank, then there must be a process time on each step-facility card in the step packet.

(4) Columns 29 through 32. Explicit default next step. This is a literal field. The word EXIT should be coded here if the EXIT step is desired. Any entry in this field, other than the word EXIT or four blanks to indicate system default, must be the step number of a step appearing in the same process file as the step card.

(5) Columns 33 through 36. Explicit default probability of splitting. This is a real field. A negative value in this field is automatically changed to zero and a value larger than one is automatically changed to one. Default is zero.

(6) Columns 37 through 40. Explicit default split step. This is a literal field. The SCRAP step may be specified here by coding SCRP. Any entry in this field, other than SCRP or four blanks, must be the step number of a step appearing in the same process file as the step card.

(7) Remainder of card. Not read by the program.

Explicit default entries are checked for accuracy only when the explicit default is actually used.

The step card is followed by step-facility cards, one for each facility used in the step. Each step-facility card therefore defines a step-facility combination. The format for the step-facility cards is:

(1) Column 1. This is a literal field. A blank in Column 1 indicates that another step-facility card follows; any non-blank character indicates the last card in the step packet.

(2) Columns 2 through 9. The facility serial number. This is a literal field with no default. It is an error to specify a serial number not listed in the facility file.

(3) Columns 10 through 17. Process time in hours. This is a real field. Process times, whether defined explicitly or by default, must be positive. A zero value in this field causes default.

(4) Columns 18 through 21. Next step. Comments applying to the explicit default next step apply here.

(5) Columns 22 through 25. Probability of splitting. This is a real field. A negative value in this field is automatically changed to zero. A zero value causes default. A value larger than one is automatically changed to one.

(6) Columns 26 through 29. Split step. This is a literal field. The contents of this field are ignored if the probability of splitting is zero. If the SCRAP step is desired, SCRP should be coded here. Any entry in this field, other than SCRP or four blanks to indicate default, must be the step number of a step appearing in the same process file.

(7) Remainder of card. Not read.

The order of the step packets determines the defaults of the next-step attribute, and also the order of the steps in the output listings. The step numbers need not have any relation to the order in which the steps are executed. For example, step number 0081 may occur before step number 0080, if the user so specifies.

Each process file must be self-contained. It is not permissible, for example, for a step-facility combination in one process file to refer to a step in another process file.

Arrangement of the Input Files

The input files are placed behind the source and/or object cards of the program and their associated control cards. In FORTRAN, data files are given special names, which are of the form FTnnF001. nn represents a two-digit number, called the file number. The file number is used by the program to identify the file. At most installations, including the Benet Weapons Lab computer, data file number 05 also has the name SYSIN.

The input files for PRDLN have the following file numbers:

05 SYSIN file

08 Crew file

09 Facility file

10 Process file for the first process file

11 Process file for the second process file (if any); etc.

The file numb for the process files begin at 10, and continue on as required. The process files must be numbered in order of priority of the item types. Thus, file number 10 is assumed to be the process file of an item type of highest priority. Process file number n must have the same or lower priority than process file number n - 1.

The user must also specify one "DUMMY" process file. This is an empty file labeled "DUMMY" and tells the program that there are no more process files.

Shown below is a possible arrangement of input files for a run with two process files:

```
(Job control cards, program cards and link-editor control cards)

//GØ.FT08F001 DD *

(Crew cards)

//GØ.FT09F001 DD *

(Facility cards)

//GØ.FT10F001 DD *

(Higher priority process file)

//GØ.FT11F001 DD *

(Second process file)

//GØ.FT12F001 DD DUMMY

//GØ.SYSIN DD *

(SYSIN file)

/*
```

Note that file 12 is a dummy file, indicating there are only two process files. If there are n process files, then file 10+n should be declared a dummy file.

System Limitations

The following are the maximum values allowed for the current version of PRDLN for various parameters:

number of months	60
number of shifts	3
total item storage capacity	500
hours per shift	no limit
days per month	no limit
number of crews	10

number of workers per crew per shift	no limit
number of facilities	100
number of steps*	150
number of step-facility combinations*	600
number of item types	5
number of item inputs*	10

*totalled over all production processes.

Any attempt to go over the system limitations will cause the program to produce error messages and stop.

Example of Input Data

Table A6 is an illustration of a possible input data deck. A brief description of some features of the deck will be given below.

The crew file follows the GO.FT08F001 statement. There are three crews named MACHINE, REPAIR and FINISH. The number of crew members on each shift follows the name. Thus, the MACHINE crew has 10 members on the first shift, 5 on the second and 2 on the third.

The facility file follows the GØ.FT09F001 statement.

The first facility is the cutter, serial number AAB00002. Its operator crew is the MACHINE crew, its maintenance crew is the REPAIR crew. It has a MOTTF of 401.5 hours and a MTTR of 3.2 hours. The other entries on the card are left blank, indicating default values: minimum entry, maximum entry, maximum capacity and number of operators are all 1, the facility is locking and halts at shift change.

The third facility, the paint brush, has no entries for MOTTF and MTTR. So it never fails. Since a facility that never fails does not require a maintenance crew, no maintenance crew is specified.

The ovens have a minimum entry of 5, a maximum entry of 10 and maximum capacity of 50. This means that items are put into the ovens in batches, each batch containing no less than 5 items and no more that 10. The ovens are also continuous and unlocking.

The first process file follows the GØ.FT10F001 card. The items for this process file are called "Widget" and have the highest priority. There are two inputs specified (2nd and 3rd cards). The first input specifies that 30 widgets are to be introduced every 48 hours, beginning immediately. The second input specifies 20 widgets every 48 hours beginning 24 hours after the start of simulation at step 0002. Since from the SYSIN file (see below) it follows that there are 24 hours in a day, the inputs in effect specify that widgets are to be introduced at the start of the day, with 30 widgets being introduced every other day and 20 widgets on the days in between.

The first step packet is for step 0001, "lathe ends". There are four facilities available for performing this task, those with serial numbers AAC34125, AAC49502, AAC49512 and AAC49504. The step requires 1.5 hours on AAC34125 but only 0.5 hour on the others. Widgets worked on by AAC34125 will go on to step 0005. The cards for the other facilities have no next-step entry; consequently, widgets worked on by other facilities are routed to 0003, which is the next step specified on the step card.

The step card for step 0005, "cut slot", specifies that the output of that step is to be split. As the step facility cards have no splitting entries, the split applies to both facilities used for this step. The probability of splitting is 0.3 and the split step is 0007. This means that 0.3, or 30%, of the items passing through step 0005 will be routed to step 0007 upon completion of step 0005. The remaining 70% will go on normally to the next step, defined by system default to be step 0006.

Step 0010, "drill mid holes", also has a split. However, here the split step is "SCRP", the SCRAP step. The probabilty of splitting is 0.01, or 1%. So 1% of the item passing through step 0010 will be scrapped after completion of step 0010.

According to the GØ.FT11F001 card, file 11, which would normally contain the second process file, is a dummy, i.e., it is empty. So there are no more process files.

The SYSIN file follows the GØ.SYSIN card. The first card is the title that will appear on each page of output. The second contains the number of days in a month, 30. The third card specifies that the results of the simulation are to be based on 12 months, that 2 months are to be allowed for warm-up to get to a steady state condition (giving 14 months altogether, the results of the first 2 being discarded)and that the total item storage capacity is 200.

The shift cards follow. The first shift is called "Days" and lasts for 8 hours. The second shift is called "Evenings" and lasts for 8 hours, etc.

TABLE A1

SYSIN File Formats

Card Column	Contents	Default	Format
	Card 1		
1 - 80	Title	80 blanks	Literal (10A8)
	Card 2		
1 - 4	Number of days per month	20	Integer (I4)
5 - 80	Not read		
	Card 3		
1 - 4	Number of months' simulation on which output is to be based	1	Integer (I4)
5 - 8	Number of months for warm-up	1	Integer (I4)
9 - 12	Total Item Storage Capacity	500	Integer (I4)
13 - 16	Random generator starting point	0	Integer (I4)
17 - 80	Not read		
	Card 4 and following (shift cards)		
1 - 8	Shift name	None	Literal (A8)
9 - 16	Hours in the shift	None	Real (E8.0)
17 - 80	Not read		

TABLE A2

Crew Card Format

Card Column	Contents	Default	Format
1 - 8	Crew name	None	Literal (A8)
9 - 12	Number of members on first shift	0	Integer (I4)
13 - 16	Number of members on second shift (if any)	0	Integer (I4)
17 - 20	Number of members on third shift (if any)	0	Integer (I4)
21 - 80	Not read		

TABLE A3

Facility Card Format

Card Column	Contents	Default	Format
1 - 8	Serial number	None	Literal (A8)
9 - 24	Facility name	None	Literal (2A8)
25 - 32	Operator crew	None	Literal (A8)
33 - 40	Maintenance crew	None	Literal (A8)
41 - 48	Mean Operating Time to Failure (MOTTF)	No failure	Real (E8.0)
49 - 56	Mean Time to Repair (MTTR)	0	Real (E8.0)
57 - 60	Minimum Entry (MINENT)	1	Integer (I4)
61 - 64	Maximum Entry (MAXENT)	MAXENT=MINENT	Integer (I4)
65 - 68	Maximum Capacity (MAXCAP)	MAXCAP=MAXENT	Integer (I4)
69 - 72	Number of Operators*	1	Integer (I4)
73	Locking or Unlocking**	Locking	Literal (A1)
74	Disposition at Shift Change for Operation***	Halt	Literal (A1)
75 - 78	Number of Repairmen*	1	Integer (I4)
79	Disposition at Shift Change for Repair***	Halt	Literal (A1)

* To specify none, place a negative number in this field.
** Any non-blank character in CC73 indicates unlocking.
*** Any non-blank character indicates continuous.

TABLE A4

Step Card Format

Card Column	Contents	Default	Format
1 - 4	Step number	None	Literal (A4)
5 - 20	Step name	None	Literal (2A8)
21 - 28	Process time	None	Real (E8.0)
29 - 32	Next step	*	Literal (A4)
33 - 36	Probability of splitting	0	Real (E4.0)
37 - 40	Split step	SCRAP	Literal (A4)
41 - 80	Not read		

* Default is the next step physically following, if there is one; otherwise EXIT.

TABLE A5

Step-Facility Card Format

Card Column	Contents	Default	Format
1	Type of next card*	Blank	Literal (A1)
2 - 9	Facility serial number	None	Literal (A8)
10 - 17	Process time	**	Real (E8.0)
18 - 21	Next step	***	Literal (A4)
22 - 25	Probability of splitting	***	Real (E4/0)
26 - 29	Split step	***	Literal (A4)
30 - 80	Not read		

* A blank indicates that the next card is also a step-facility card; any non-blank character indicates that the next card is not a step-facility card.

** Default is provided by the process-time entry on the step card, if one is provided; otherwise there is no default.

*** Default is provided by the corresponding entries on the step card or by their defaults.

TABLE A6

Sample Input Deck

```
C         1111111111222222222233333333334444444444555555555566666666667777777778
C1234567890123456789012345678901234567890123456789012345678901234567890123456789 0

 //GO.FT08F001 DD *
 MACHINE   10   5   2
 REPAIR     3   3   2
 FINISH     8   4   2
 //GO.FT09F001 DD *
 AABC0002CUTTER          MACHINE REPAIR  401.25  3.2
 AABC0005CUTTER          MACHINE REPAIR  837.6   2.3
 C56789A PAINT BRUSH     FINISH
 89-5723 OVEN            FINISH  REPAIR  1578.   19.3       5  10  50    **
 89-5725 OVEN            FINISH  REPAIR  2346.   25.        5  10  50    **
 C56789B PAINT BRUSH     FINISH
 AAC34125TYPE A LATHE    MACHINE REPAIR  149.5   7.3                          2*
 AAC49502TYPE B LATHE    MACHINE REPAIR  678.    12.9                   2
 AAC49504TYPE B LATHE    MACHINE REPAIR  729.    3.4                    2
 AAC49512TYPE B LATHE    MACHINE REPAIR  412.6   3.5                    2
 CD9-A58 DRILL           MACHINE REPAIR  198.4   .25
 CD9-A62 DRILL           MACHINE REPAIR  86.5    .3
 DE8A37  FORK LIFT       FINISH  REPAIR  922.    3.5        2
 81C56C SANDER           MACHINE REPAIR  642.0   1.8
 //GO.FT10F001 DD *
 WIDGET
    30 48.
 *  20 48.   .24.     0002
 0001LATHE ENDS      0003
  AAC34125 1.5    0005
  AAC49502 0.5
  AAC49512 0.5
 *AAC49504 0.5
 0002LATHE ENDS
  AAC49512 0.5

C         1111111111222222222233333333334444444444555555555566666666667777777778
C1234567890123456789012345678901234567890123456789012345678901234567890123456789 0
```

SAMPLE Input (continued)

```
C         1111111111222222222233333333334444444444555555555566666666667777777778
C12345678901234567890123456789012345678901234567890123456789012345678901234567890

*AAC49504 0.5
0003SAND ENDS       .5
*81C056C
0005CUT SLOT        .75         .3  0007
 AABC0005
*AABC0002
0006RELATHE         1.      001C
 AAC34125
*AAC49504
0007RELATHE         1.2
*AAC49502
0010DRILL MID HOLES .75         .01 SCRP
 CD9-A58
*CD9-A62
005AGO TO BLDG 5    .5
*DE8A37
006APAINT           1.
 C56789A
*C56789B
008ABAKE            5.
 89-5723
*89-5725
//GO.FT11F001 DD DUMMY
//GO.SYSIN DD *
16 OCT 78 -- SAMPLE PRODUCTION SIMULATION
  30
  12   2 200
DAYS    8.
EVENINGS8.
NIGHTS  8.

C         1111111111222222222233333333334444444444555555555566666666667777777778
C12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

APPENDIX B

SAMPLE OUTPUT FROM PRDLN

In this appendix, the output from the program PRDLN will be described. As an example, we use the output given by the input deck used as an illustration in Appendix A. This output is shown in Figure B1.

Some general comments: First, the output has been designed so that each page may be reproduced on an 8-1/2" X 14" sheet of paper, the 14" side on the horizontal. Second, the date that appears on each page of the sample output was taken from the title card of the input deck. The program will not produce dates on its own. The page numbers are produced automatically. The program produces all output on data set 6, which is assumed to have logical records of 133 bytes fixed length with ASA control characters in the first byte of each logical record. The user may direct output as desired by modifying the FT06F001 data definition in the GØ step, provided the desired output medium can handle logical records of fixed length of 133 bytes.

On the sample output, each block of output conveniently fit on one page. If a block of output cannot fit entirely on one page, then continuation pages with the appropriate headings are produced. Page numbering is sequential. Consequently, the "facility failure data", for example, which appears on the sample output on page 5, may not be on page 5 in all output listings. Recall that the program requires a "warm-up" period to get to a steady state condition. The results of the warm-up period are <u>not</u> included in and do <u>not</u> contribute to any of the statistics in the output.

All times mentioned in the output listings are in hours, unless specifically labelled otherwise.

General System Information and Shift and Crew Data

The first block of data, appearing on page 1 in the sample, contains general information and data concerning shifts and crews. All of this data up to and including "numbers of crew members" are taken from the input data, and should be self-explanatory.

The table labelled "average number of active workers per unit item" is generated by the program. The numbers in these tables are time averages. In general, let f(t) be some function of time, t. If t_1 and t_2 are times and $t_1 < t_2$, then the time average of the function f over the time interval from t_1 to t_2 is defined as:

$$\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} f(t)dt$$

The time average gives a "typical" or "central" value of the function f as it varies over time, just as the familiar arithmetic average gives a "typical" or "central" value of a set of numbers.

For the "number of active workers per unit time" table, the function f(t) is the number of active workers at time t. The figures in the table provide one measure of how busy the workers are. For example, on the "machine" crew on day shift, 8.91 workers out of 10 are active, on the average. Consequently, the workers on this shift and crew are kept fairly busy. On the other hand, on the "repair" crew on day shift, only 0.11 workers out of 3 are active, on the average. This would suggest that the "repair" crew might be overstaffed on day shift.

Production Processes

The next blocks of data to be printed are the production processes. In the sample, there is only one production process, which appears on page 2. The data on this page with the exception of the "percent taken" column are taken from the input deck. Note that all values not specified in the input deck have been filled in with their defaults.

Recall that the facilities for each step are alternatives. For each step, only one of the listed facilities will be used for each item passing through the step. The "percent taken" column gives the percentage of times that a particular alternative was selected. For example, in the first step, number 0001, these are four facilities. The first one, serial AAC34125, was selected 11.3% of the time. The second one, serial AAC49502, was selected 24.6% of the time, etc.

Facility Characteristics

The next block of data is the facility characteristics, which appear on page 3 in the sample. This table lists the options chosen by the user, either explicitly or by default, for each facility.

Facility Failure Data

The next block of data is the facility failure data, which appears on page 4 of the sample. These data consist of both input data and values calculated by the program from the simulation. First let us define some terms.

A facility is "in use" or is being "operated" whenever it is <u>actively</u> processing items. The facility is not considered to be "in use" when it is in a halted or down condition. The facility is "waiting for maintenance" when it has gone down (i.e., experienced a failure) but repair or maintenance has not yet begun. The facility is in "active maintenance" whenever it is down and repairmen are actually working on it to restore it to service. The terms "repair" and "maintenance" are used interchangeably, since the current version of PRDLN does not distinguish between scheduled and unscheduled outages. The "total time" will refer to the total time over which the facility was observed.

The "mean operating time to failure" (MOTTF) is defined by:

$$\text{MOTTF} = \frac{\text{total time in use}}{\text{number of failures}}$$

There are two MOTTF entries labelled "input" and "simulated". The "input" column is the MOTTF specified by the user in the input deck. This column is filled with asterisks if the user specified that the facility never failed. The "simulated" MOTTF is the MOTTF observed by the program during the simulation. The input and simulated values will generally be different because the program generates random variables for times between failure.

The "mean time to fail" (MTTF) is given by:

$$\text{MTTF} = \frac{\text{total time not in active maintenance}}{\text{number of failures}}$$

MTTF is calculated from the simulation data. Note the difference between MOTTF and MTTF: The MOTTF is the average time <u>in use</u> between failures, whereas MTTF is the average <u>total</u> time between failures, excluding time in active maintenance. Both MOTTF and MTTF are measures of how often a facility fails, but they are not equivalent and not equally useful in all contexts. For example, we may have a facility with a fairly low MOTTF, but which is used relatively little. This means that one gets relatively little use out of the facility between failures. However, because it is used relatively little, its failures will be far apart in absolute time, i.e., its MTTF will be high. The MTTF is of greater use than MOTTF in the allocation of repair and maintenance resources, since a facility that fails relatively seldom (high MTTF) will make relatively little demand on the repair resources, regardless of its MOTTF.

The simulated MOTTF and MTTF columns are filled with asterisks whenever the facility has not failed during the simulation.

The "mean time to repair" (MTTR) is defined by:

$$\text{MTTR} = \frac{\text{total time in active maintenance}}{\text{number of failures}}$$

The MTTR is a measure of how long the facility stays down after it has failed. MTTR, like MOTTF, is given as "input" and as "simulated".

The input MTTR is the value specified by the user in the input deck. This column is filled with asterisks if the user specified that the facility never fails. The simulated MTTR is the MTTR actually calculated from the simulation data. Since the program generates random variables for repair times, the input and simulated MTTR's will generally differ. The simulated MTTR column is filled with asterisks if the facility never failed during the simulation.

The "mean waiting time to maintenance" (MWTTM) is defined by:

$$\text{MWTTM} = \frac{\text{total time waiting for maintenance}}{\text{number of failures}}$$

MWTTM is calculated from the simulation results. It is one measure of the effectiveness of a maintenance policy. The MWTTM column is filled with asterisks if the facility never failed during the simulation.

The term "average number of failures per month" should be self-explanatory.

Facility Usage Data

The facility usage data is the next block of data and appears on pages 5 and 6 in the sample. The terms used are defined by:

$$\text{utilization rate} = \frac{\text{total time in use}}{\text{total time}}$$

$$\text{maintenance rate} = \frac{\text{total time in active maintenance}}{\text{total time}}$$

$$\text{awaiting-maintenance rate} = \frac{\text{total time waiting for maintenance}}{\text{total time}}$$

idle rate = 1 - sum of the other three rates

Each of the four rates is broken down by shift. The "overall" columns give the rates not broken down by shift. For example, the first facility listed in the sample (serial number AAB00002) has an overall utilization rate of 25.5%. This means that 25.5% of the time AAB00002 was in use. Its overall maintenance rate is 0.4%. This means that 0.4% of the time AAB00002 was in active maintenance. The idle and awaiting maintenance rates are similarly interpreted.

Queue Data

The next block of data, queue data, appears in the sample on page 7. Recall that each step in each production process has a queue--a waiting area where items wait for service. The items are placed in queue for a step as soon as they complete service on the previous step and leave the queue as soon as they can obtain service at a facility listed for the step. Note that an item being processed in a facility is not in any queue and does not return to queue if the facility halts.

The "queue length" is the number of items in a queue at a given moment. The "waiting time" of an item is the amount of time that the item spends waiting in the queue. The queue data lists for each step an average queue length and an average waiting time. The average queue length is a time average, and is a measure of how many items are "usually" waiting at the queue. Note that average queue length is not a maximum queue length. It is a time average. For example, an unusually long queue which lasts for a very short time may not have much effect on the average.

Average queue length is extremely useful in identifying "bottlenecks" in the production process. An unusually high average queue length can generally be taken to indicate that the resources available at that step are not adequate to handle the demands on them.

The average waiting time is a per item average. It is the average time that each item waits in the queue. It does not indicate how full the queue is. Note further that many items can be waiting simultaneously in the same queue. Consequently, the product of average queue length and average waiting time has no useful interpretation as far as the author knows. In particular, this product does not represent an average time between arrivals in the queue or any other such quantity.

Production Data

The final block of data is the production data, shown on page 8 in the sample. An item is said to be "produced" when it passes through the EXIT step. The EXIT step is a programmatically-created step added to the end of each production process. (Recall that items can leave a production process only be passing through either the EXIT step or the SCRAP step. Items passing through the SCRAP step are not added to the production figures.) The figures in this block of data do not include the warm-up months.

Simulation results begin with the "average number of items produced per month". This term should be self-explanatory. The "average number of items in the system per unit time" is a time average. The number of items in the system at any time includes all the items in the queues and in the facilities.

Under "number of items produced each month in chronological order" is a list of items produced. The first entry is the number of items produced in the first month after warm-up. The second entry is the number of items produced in the second month after warm-up, etc. A noticeable trend in these values (other than cyclic trends) may mean that the system has not reached a steady-state condition after warm-up.

The last table in the block of data summarizes the production figures. "N" in the column headings refers to the numbers listed in the first column. The entries in the last column, the "estimated probability of producing N or more items in one month" is calculated by formula:

$$\frac{\text{number of months in which N or more items were produced}}{\text{total number of months}}$$

This last column is important in determining how often a production goal will be met. For example, if the widget manufacturer was required to produce 740 widgets each month, the simulation suggests that he could meet this requirement about 83% of the time.

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

CURRENT SIMULATION IS OF 14 MONTHS TOTAL OPERATION
RESULTS ARE BASED ON THE LAST 12 MONTHS OPERATION
TOTAL ITEM STORAGE CAPACITY IS 200 ITEMS
IN THE FOLLOWING: ONE DAY IS 24.00 HOURS
ONE MONTH IS 30 DAYS
ALL TIMES ARE IN HOURS

SHIFT & CREW INFORMATION

SHIFT NAMES:	DAYS	EVENINGS	NIGHTS
HOURS IN SHIFT	8.00	8.00	8.00

CREW NAME	NUMBER OF CREW MEMBERS DAYS	EVENINGS	NIGHTS
MACHINE	10	5	2
REPAIR	3	3	2
FINISH	8	4	2

	AVERAGE NUMBER OF ACTIVE WORKERS PER UNIT TIME DAYS	EVENINGS	NIGHTS
MACHINE	8.91	4.98	1.95
REPAIR	0.11	0.14	0.10
FINISH	2.51	2.23	1.45

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

ITEM TYPE: WIDGET

PRIORITY: 1

INPUT SCHEDULE

30 ITEMS EVERY 48.00 HOURS AFTER 0.0 HOURS AT STEP 0001
20 ITEMS EVERY 48.00 HOURS AFTER 24.00 HOURS AT STEP 0002

PRODUCTION PROCESS STEP	FACILITIES AVAILABLE		PROCESS TIME (HRS)	NEXT STEP	PROBABILITY OF SPLIT	SPLIT STEP	PERCENT TAKEN
0001 LATHE ENDS	AAC34125	TYPE A LATHE	1.50	0005	0.0		11.3
	AAC49502	TYPE B LATHE	0.50	0002	0.0		24.6
	AAC49512	TYPE B LATHE	0.50	0002	0.0		32.9
	AAC49504	TYPE B LATHE	0.50	0002	0.0		31.2
0002 LATHE ENDS	AAC49512	TYPE B LATHE	0.50	0003	0.0		64.6
	AAC49504	TYPE B LATHE	0.50	0003	0.0		35.4
0003 SAND ENDS	810056C	SANDER	0.50	0005	0.0		100.0
0005 CUT SLOT	AAB00005	CUTTER	0.75	0006	0.300	0007	67.3
	AAB00002	CUTTER	0.75	0006	0.300	0007	32.7
0006 RELATHE	AAC34125	TYPE A LATHE	1.00	0010	0.0		83.3
	AAC49504	TYPE B LATHE	1.00	0010	0.0		16.7
0007 RELATHE	AAC49502	TYPE B LATHE	1.20	0010	0.0		100.0
0010 DRILL MID HOLES	CD9-A58	DRILL	0.75	005A	0.010	SCRAP	68.6
	CD9-A62	DRILL	0.75	005A	0.010	SCRAP	31.4
005A GO TO BLDG 5	DE8A37	FORK LIFT	0.50	006A	0.0		100.0
006A PAINT	C56789A	PAINT BRUSH	1.00	008A	0.0		55.2
	C56789B	PAINT BRUSH	1.00	008A	0.0		44.8
008A BAKE	89-5723	OVEN	5.00	EXIT	0.0		97.5
	89-5725	OVEN	5.00	EXIT	0.0		2.5

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

FACILITY CHARACTERISTICS

		OPERATOR CREW	REPAIR CREW	MINIMUM ENTRY	MAXIMUM ENTRY	MAXIMUM CAPACITY	NUMBER OF OPERATORS	OPERATING MODE	NUMBER OF REPAIRMEN	DISPOSITION AT SHIFT CHANGE OPERATION	REPAIR
AAB00002	CUTTER	MACHINE	REPAIR	1	1	1	1	LOCKED	1	HALT	HALT
AAB00005	CUTTER	MACHINE	REPAIR	1	1	1	1	LOCKED	1	HALT	HALT
C567894	PAINT BRUSH	FINISH		1	1	1	1	LOCKED	0	HALT	CONTINUE
89-5723	OVEN	FINISH	REPAIR	5	10	50	1	UNLOCKED	1	CONTINUE	HALT
89-5725	OVEN	FINISH	REPAIR	5	10	50	1	UNLOCKED	1	CONTINUE	HALT
C567898	PAINT BRUSH	FINISH		1	1	1	1	LOCKED	0	HALT	CONTINUE
AAC34125	TYPE A LATHE	MACHINE	REPAIR	1	1	1	1	LOCKED	2	HALT	CONTINUE
AAC49502	TYPE B LATHE	MACHINE	REPAIR	1	1	1	2	LOCKED	1	HALT	HALT
AAC49504	TYPE B LATHE	MACHINE	REPAIR	1	1	1	2	LOCKED	1	HALT	HALT
AAC49512	TYPE B LATHE	MACHINE	REPAIR	1	1	1	2	LOCKED	1	HALT	HALT
C09-A56	DRILL	MACHINE	REPAIR	1	1	1	1	LOCKED	1	HALT	HALT
C09-A62	DRILL	MACHINE	REPAIR	1	1	1	1	LOCKED	1	HALT	HALT
DE8437	FORK LIFT	FINISH	REPAIR	2	2	2	1	LOCKED	1	HALT	HALT
810056C	SANDER	MACHINE	REPAIR	1	1	1	1	LOCKED	1	HALT	HALT

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

FACILITY FAILURE DATA
ALL TIMES ARE IN HOURS

		MEAN OPERATING TIME TO FAIL INPUT	MEAN OPERATING TIME TO FAIL SIMULATED	MEAN TIME TO FAIL	MEAN TIME TO REPAIR INPUT	MEAN TIME TO REPAIR SIMULATED	MEAN WAITING TIME TO MAINTAINANCE	AVERAGE NUMBER OF FAILURES PER MONTH
AAB00002	CUTTER	401.25	441.15	1720.29	3.20	7.71	0.0	0.42
AAB00005	CUTTER	837.60	908.85	1725.60	2.30	2.40	0.0	0.42
C56789A	PAINT BRUSH	*********	*********	*********	*********	*********	*********	0.0
89-5723	OVEN	1578.00	1089.17	1406.12	19.30	33.88	0.0	0.50
89-5725	OVEN	2346.00	*********	*********	25.00	*********	*********	0.0
C56789B	PAINT BRUSH	*********	*********	*********	*********	*********	*********	0.0
AAC34125	TYPE A LATHE	149.50	136.93	185.40	7.30	6.60	0.0	3.75
AAC49502	TYPE B LATHE	678.00	650.38	1426.48	12.90	13.52	0.0	0.50
AAC49504	TYPE B LATHE	729.00	422.69	1076.57	3.40	3.43	0.0	0.67
AAC49512	TYPE B LATHE	412.60	899.87	2153.99	3.50	6.01	0.0	0.33
CD9-A58	DRILL	198.40	272.51	508.02	0.25	0.22	0.0	1.42
CD9-A62	DRILL	86.50	111.39	454.50	0.30	0.24	0.0	1.58
DE8A37	FORK LIFT	922.00	2225.59	8639.81	3.50	0.19	0.0	0.08
810056C	SANDER	642.00	1049.00	2158.68	1.80	1.32	0.0	0.33

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

FACILITY USAGE DATA

		UTILIZATION RATE				MAINTAINANCE RATE			
		OVERALL	DAYS	EVENINGS	NIGHTS	OVERALL	DAYS	EVENINGS	NIGHTS
AAB00002	CUTTER	25.5%	35.3%	35.2%	6.1%	0.4%	0.7%	0.4%	0.3%
AAB00005	CUTTER	52.6%	63.1%	64.6%	30.0%	0.1%	0.1%	0.0%	0.3%
C56789A	PAINT BRUSH	56.9%	66.3%	57.6%	46.8%	0.0%	0.0%	0.0%	0.0%
89-5723	OVEN	75.6%	82.2%	80.0%	64.7%	2.4%	2.5%	2.3%	2.2%
89-5725	OVEN	2.0%	2.3%	1.9%	1.8%	0.0%	0.0%	0.0%	0.0%
C567890	PAINT BRUSH	46.1%	65.6%	57.6%	15.2%	0.0%	0.0%	0.0%	0.0%
AAC34125	TYPE A LATHE	71.3%	93.8%	73.5%	46.7%	3.4%	2.9%	4.6%	2.8%
AAC49502	TYPE B LATHE	45.2%	86.2%	32.1%	17.3%	0.9%	1.0%	0.9%	0.9%
AAC49504	TYPE B LATHE	39.1%	98.4%	17.0%	2.0%	0.3%	0.5%	0.4%	0.0%
AAC49512	TYPE B LATHE	41.7%	85.9%	38.5%	0.6%	0.3%	0.2%	0.4%	0.3%
CD9-A58	DRILL	53.6%	63.3%	54.4%	43.2%	0.0%	0.0%	0.1%	0.0%
CD9-A62	DRILL	24.5%	43.2%	21.1%	9.3%	0.1%	0.1%	0.1%	0.0%
DE3A37	FORK LIFT	25.8%	34.5%	26.0%	16.8%	0.0%	0.0%	0.0%	0.0%
810256C	SANDER	48.6%	51.8%	73.8%	20.1%	0.1%	0.0%	0.1%	0.1%

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

FACILITY USAGE DATA (CONT.)

		IDLE RATE				AWAITING-MAINTAINANCE RATE			
		OVERALL	DAYS	EVENINGS	NIGHTS	OVERALL	DAYS	EVENINGS	NIGHTS
AABC0002	CUTTER	74.0%	64.0%	64.5%	93.6%	0.0%	0.0%	0.0%	0.0%
AABC0005	CUTTER	47.3%	36.8%	35.4%	69.6%	0.0%	0.0%	0.0%	0.0%
C567890A	PAINT BRUSH	43.1%	33.7%	42.4%	53.2%	0.0%	0.0%	0.0%	0.0%
89-5723	OVEN	22.0%	15.3%	17.7%	33.1%	0.0%	0.0%	0.0%	0.0%
89-5725	OVEN	98.0%	97.7%	98.1%	98.2%	0.0%	0.0%	0.0%	0.0%
C567898	PAINT BRUSH	53.9%	34.4%	42.4%	84.8%	0.0%	0.0%	0.0%	0.0%
AAC34125	TYPE A LATHE	25.2%	3.3%	22.0%	50.4%	0.0%	0.0%	0.0%	0.0%
AAC49502	TYPE B LATHE	53.9%	12.8%	67.0%	81.9%	0.0%	0.0%	0.0%	0.0%
AAC49504	TYPE B LATHE	60.5%	1.0%	82.7%	97.9%	0.0%	0.0%	0.0%	0.0%
AAC49512	TYPE B LATHE	58.1%	13.9%	61.1%	99.2%	0.0%	0.0%	0.0%	0.0%
CD9-A56	DRILL	46.3%	35.6%	45.5%	56.8%	0.0%	0.0%	0.0%	0.0%
CD9-A62	DRILL	75.5%	56.8%	78.9%	90.7%	0.0%	0.0%	0.0%	0.0%
DERA37	FORK LIFT	74.2%	65.5%	74.0%	83.2%	0.0%	0.0%	0.0%	0.0%
810056C	SANDER	51.4%	48.2%	26.1%	79.9%	0.0%	0.0%	0.0%	0.0%

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

ITEM TYPE: WIDGET

STEP	AVERAGE QUEUE LENGTH	AVERAGE WAITING TIME (HRS)
0001 LATHE ENDS	1.45	2.30
0002 LATHE ENDS	5.16	5.32
0003 SAND ENDS	2.91	2.99
0005 CUT SLOT	2.28	2.19
0006 RELATHE	2.43	3.34
0007 RELATHE	2.30	7.37
001C DRILL MID HOLES	1.82	1.75
005A GO TO BLDG 5	0.66	0.64
006A PAINT	0.55	0.53
008A BAKE	1.99	1.93

16 OCT 78 -- SAMPLE PRODUCTION SIMULATION

ITEM TYPE: WIDGET

PRODUCTION SIMULATION OF 12 MONTHS
MAXIMUM STORAGE CAPACITY FOR THIS TYPE: 200
AVERAGE NUMBER OF ITEMS PRODUCED PER MONTH: 741.67
AVERAGE NUMBER OF ITEMS IN THE SYSTEM PER UNIT TIME: 32.49

NUMBER OF ITEMS PRODUCED EACH MONTH IN CHRONOLOGICAL ORDER
740, 735, 745, 740, 740, 745, 740, 745, 740, 735,
750, 745

N	NUMBER OF MONTHS IN WHICH EXACTLY N ITEMS WERE PRODUCED	ESTIMATED PROBABILITY OF PRODUCING N OR MORE ITEMS IN ONE MONTH
735	2	100%
740	5	83%
745	4	42%
750	1	8%

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
COMMANDER	1
CHIEF, DEVELOPMENT ENGINEERING BRANCH	1
ATTN: DRDAR-LCB-DA	1
-DM	1
-DP	1
-DR	1
-DS	1
-DC	1
CHIEF, ENGINEERING SUPPORT BRANCH	1
ATTN: DRDAR-LCB-SE	1
-SA	1
CHIEF, RESEARCH BRANCH	2
ATTN: DRDAR-LCB-RA	1
-RC	1
-RM	1
-RP	1
CHIEF, LWC MORTAR SYS. OFC.	1
ATTN: DRDAR-LCB-M	1
CHIEF, IMP. 81MM MORTAR OFC.	1
ATTN: DRDAR-LCB-I	1
TECHNICAL LIBRARY ATTN: DRDAR-LCB-TL	5
TECHNICAL PUBLICATIONS & EDITING UNIT ATTN: DRDAR-LCB-TL	2
DIRECTOR, OPERATIONS DIRECTORATE	1
DIRECTOR, PROCUREMENT DIRECTORATE	1
DIRECTOR, PRODUCE ASSURANCE DIRECTORATE	1

NOTE: PLEASE NOTIFY ASSOC. DIRECTOR, BENET WEAPONS LABORATORY, ATTN: DRDAR-LCB-TL, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH & DEVELOPMENT ATTN: DEP FOR SCI & TECH THE PENTAGON WASHINGTON, D.C. 20315	1
COMMANDER US ARMY MAT DEV & READ. COMD ATTN: DRCDE 5001 EISENHOWER AVE ALEXANDRIA, VA 22333	1
COMMANDER US ARMY ARRADCOM ATTN: DRDAR-LC	1
-LCA (PLASTICS TECH EVAL CEN)	1
-LCE	1
-LCM	1
-LCS	1
-LCW	1
-TSS(STINFO) DOVER, NJ 07801	2
COMMANDER US ARMY ARRCOM ATTN: DRSAR-LEP-L ROCK ISLAND ARSENAL ROCK ISLAND, IL 61299	1
DIRECTOR US Army Ballistic Research Laboratory ATTN: DRDAR-TSB-S (STINFO) ABERDEEN PROVING GROUND, MD 21005	1
COMMANDER US ARMY ELECTRONICS COMD ATTN: TECH LIB FT MONMOUTH, NJ 07703	1
COMMANDER US ARMY MOBILITY EQUIP R&D COMD ATTN: TECH LIB FT BELVOIR, VA 22060	1

	NO. OF COPIES
COMMANDER US ARMY TANK-AUTMV R&D COMD ATTN: TECH LIB - DRDTA-UL	1
MAT LAB - DRDTA-RK WARREN MICHIGAN 48090	1
COMMANDER US MILITARY ACADEMY ATTN: CHMN, MECH ENGR DEPT WEST POINT, NY 10996	1
COMMANDER REDSTONE ARSENAL ATTN: DRSMI-RB	2
-RRS	1
-RSM ALABAMA 35809	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SARRI-ENM (MAT SCI DIV) ROCK ISLAND, IL 61202	1
COMMANDER HQ, US ARMY AVN SCH ATTN: OFC OF THE LIBRARIAN FT RUCKER, ALABAMA 36362	1
COMMANDER US ARMY FGN SCIENCE & TECH CEN ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB - DRXMR-PL WATERTOWN, MASS 02172	2

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT)

	NO. OF COPIES
COMMANDER US ARMY RESEARCH OFFICE P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709	1
COMMANDER US ARMY HARRY DIAMOND LAB ATTN: TECH LIB 2800 POWDER MILL ROAD ADELPHIA, MD 20783	1
DIRECTOR US ARMY INDUSTRIAL BASE ENG ACT ATTN: DRXPE-MT ROCK ISLAND, IL 61201	1
CHIEF, MATERIALS BRANCH US ARMY R&S GROUP, EUR BOX 65, FPO N.Y. 09510	1
COMMANDER NAVAL SURFACE WEAPONS CEN ATTN: CHIEF, MAT SCIENCE DIV DAHLGREN, VA 22448	1
DIRECTOR US NAVAL RESEARCH LAB ATTN: DIR, MECH DIV	1
CODE 26-27 (DOC LIB) WASHINGTON, D. C. 20375	1
NASA SCIENTIFIC & TECH INFO FAC P. O. BOX 8757, ATTN: ACQ BR BALTIMORE/WASHINGTON INTL AIRPORT MARYLAND 21240	1

	NO. OF COPIES
COMMANDER DEFENSE TECHNICAL INFO CENTER ATTN: DTIA-TCA CAMERON STATION ALEXANDRIA, VA 22314	12
METALS & CERAMICS INFO CEN BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
MECHANICAL PROPERTIES DATA CTR BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
MATERIEL SYSTEMS ANALYSIS ACTV ATTN: DRXSY-MP ABERDEEN PROVING GROUND MARYLAND 21005	1

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.